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Rapid risk assessment of plant pathogenic bacteria and protists likely to threaten agriculture, biodiversity and forestry in Zambia

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Abstract

A prioritisation study was conducted to address the lack of adequate information about potential pests likely to be introduced in Zambia and become invasive. The study was conducted by subject matter experts from relevant institutions in and outside Zambia. Although this study focused on major pest categories, this paper only addresses bacteria and Protista. A list of 306 bacterial and 10 Protista species adjudged to affect plants was generated using CABI's Horizon Scanning Tool. The 316 (total) pest species were refined to focus on pests that affect value chains important to Zambia's economy. This resulted in a final list of 133 bacteria and eight Protista. Four additional bacteria species considered of phytosanitary interest were added and all 137 bacteria and eight Protista species were subjected to a rapid risk assessment

using agreed guidelines. Vectors reported to transmit any of the pathogenic organisms were also subjected to a risk assessment. A proportion of 53% (n = 77 of 145) comprising 73 bacteria and four Protista species were reported as present in Africa. Of these, 42 (57%, n = 73) bacterial species and two (n=4) Protista species were reported in neighbouring countries. Considering a cut-off of 54, the highest scoring pests were 40 bacteria (highest score of 140) and three Protista (highest score of 125). Three actions were suggested for high-scoring pests, a detection surveillance, a pest-initiated pest risk analysis (PRA) or a detection surveillance followed by pest-initiated PRA. A "no action" was suggested where the risk was very low although, for some pathogenic organisms, a "no action" was followed by periodic monitoring. This information will contribute towards proactive prevention and management of biological invasions.

Keywords
Horizon scanning, invasive alien species, pest prioritisation, pest risk, risk assessment

Introduction

A number of alien species[1] have been introduced in sub-Saharan Africa (SSA) in the last couple of years through intentional or unintentional human-mediated activities (Faulkner et al. 2020; Uyi et al. 2021; Mulema et al. 2022). The majority of these aliens have become invasive[2] (here referred to as invasive alien species or IAS) as evidenced by their effects on agricultural productivity, human health, livelihoods and biological diversity (Early et al. 2016; Paini et al. 2016; Pratt et al. 2017). In phytosanitary terms, such organisms are considered pests[3] and classified as quarantine[4] pests if not yet widespread within a target region. The primary objective of National Plant Protection Organisations (NPPOs) is to prevent the introduction and spread of quarantine pests through regulation. The effect of IAS on agricultural productivity is characterised with loss of income due to reduced crop yields, compromised quality of harvested produce and increased management costs (Eschen et al. 2021).

For instance, Eschen et al. (2021) estimated losses associated with the invasive lepidopteran insect, *Spodoptera frugiperda* in SSA at USD 9.4 Bn annually. It has also been estimated that the invasive plant pathogenic bacterium, *Xylella fastidiosa*, will cause losses ranging from USD 1.9 to USD 5.2 Bn if no corrective measures, such as de-

1 A species introduced outside its natural past or present distribution.
2 A species whose introduction and/or spread by the human agency directly or indirectly threatens biological diversity.
3 The term "pest" is used within the context of the International Plant Protection Convention (IPPC) and refers to any species, strain, or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (International Standards for Phytosanitary Measures (ISPM) Number 5). Pathogenic agents include bacteria, fungi, oomycetes, phytoplasma, viroid and virus while animals may include arthropods, molluscs and nematodes (IPPC Secretariat 2021).
4 A pest of potential economic importance to the area endangered thereby and not yet present there or present, but not widely distributed and being officially controlled (ISPM Number 5), (IPPC Secretariat 2021).

ploying resistant cultivars and application of appropriate phytosanitary measures[5], are implemented (Schneider et al. 2020). Such phytosanitary measures include control of vectors that transmit the bacterium, suppression of inoculum and removal of infected host plants (Almeida et al. 2005; Liccardo et al. 2020; Castro et al. 2021; Quetglas et al. 2022). In SSA, management of IAS is associated with extensive indiscriminate application of mostly hazardous inorganic pesticides due to limited cost-effective and efficient pest control options (Siddiqui et al. 2023). This has resulted in the production of unsafe food and feed for human and animal consumption and reduced biodiversity due to the adverse effects of hazardous agro-chemicals on non-target species (Martinez et al. 2020).

The most cost-effective, efficient, sustainable and practical management option for IAS is through restricting entry or enabling early detection in case of entry, followed by prompt mitigation of pest spread and associated adverse effects of the IAS. However, this requires availability of adequate and up-to-date information about potential invasions (Mulema et al. 2022). Horizon scanning is one approach through which such information can be generated and availed to risk managers, policy and decision-makers (Sutherland et al. 2010, 2020; Matthews et al. 2017). It is the systematic search for potential biological invasions and an assessment of their potential impacts on the economy, society and environment considering possible opportunities for mitigating the impacts (Sutherland et al. 2008, 2010, 2020; Roy et al. 2014). Information generated from horizon scanning can be used to support planning on management of IAS at country and regional level and provide information for policy and practice (Caffrey et al. 2014).

At country level, horizon scanning has been used to prioritise IAS in countries, such as Cyprus (Peyton et al. 2019), Spain (Gassó et al. 2009; Bayón and Vilà 2019), United Kingdom (Sutherland et al. 2008), see also Great Britain (Roy et al. 2014) and recently in Ghana and Kenya (Kenis et al. 2022; Mulema et al. 2022). At the regional level, horizon scanning has been utilised in the European Union (Roy et al. 2019), Central Europe (Weber and Gut 2004) and Western Europe (Gallardo et al. 2016). CABI is also considering assessing at regional level, the risk of new IAS to the Regional Economic Blocks of the East African Community (EAC), Economic Community of West African States (ECOWAS) and Southern African Development Community (SADC). There is a paucity of information on potential biological invasions in most SSA countries resulting in reduced capacity for timely detection, mitigation and management of pertinent pest threats in the region. Therefore, the current study applies the horizon-scanning approach to generate useful pest-related information for Zambia that will enhance timely action on IAS. The study was conducted with the ultimate objective of prioritising pests that are not currently recorded as present in Zambia, but could be introduced and become invasive in future, thereby threatening the economy by negatively impacting on agriculture, biodiversity and forestry.

5 Any legislation, regulation or official procedure having the purpose to prevent the introduction or spread of quarantine pests or to limit the economic impact of regulated non-quarantine pests (ISPM Number 5), (IPPC Secretariat 2021).

The full horizon-scanning assessment covered plant pests in the categories, Arthropoda, Bacteria, Chromista, Fungi, Mollusca, Nematoda, Protista, Viruses and Viroids. Previously, lists of candidate IAS for risk assessment were generated by experts through extensive literature searches (Weber and Gut 2004; Sutherland et al. 2008; Gassó et al. 2009; Roy et al. 2014; Gallardo et al. 2016; Bayón and Vilà 2019); however, CABI has developed a Horizon Scanning Tool to support identification of pests for risk assessment. The Horizon Scanning Tool was previously applied in studies conducted in Kenya in 2018 (Mulema et al. 2022) and Ghana in 2020 (Kenis et al. 2022). The tool can be accessed directly from https://www.cabi.org/HorizonScanningTool and via the CABI Compendium (https://www.cabidigitallibrary.org/cabicompendium).

Materials and methods

Selection of pests from horizon scanning

A preliminary selection of pests that had not been reported as present in Zambia was conducted using the premium version of the Horizon Scanning Tool. In this tool, information from datasheets available in the CABI Compendium was used to generate a list of pest species that are not yet reported in the selected 'area at risk' (Zambia), but reported in specified "source areas" (such as trading partner countries). However, due to gaps in pest reporting mechanisms by some countries, non-availability of a presence record for a given pest in the area at risk is not necessarily a confirmation of a pest's absence. In the Horizon Scanning Tool, the following parameters were used.

The area at risk was identified as Zambia. This was followed by selecting areas from which likely invasive pests could be introduced (source areas). These areas included all geographical areas within all continents (Africa, Asia, Europe, North America, Oceania and South America), except Antarctica. The search under source areas could be further refined by emphasising countries with matching climatic conditions, based on the Köppen-Geiger climate classification (Rubel and Kottek 2010); however, this option was not considered because all geographical areas within all continents were selected. The search could be refined by selecting likely pathways of introduction, affected plant hosts, affected plant parts that may be used in trade, habitats, impact outcomes and type of organism. However, all these parameters were left open, except for the type of pest organism.

The type of pest organism considered for this study were bacteria, viruses (included viroids) protists, fungi and chromista (oomycetes) and invertebrates (included arthropods, molluscs and nematodes). Other pest categories although not considered for this study, were plants, vertebrates and diseases of unknown aetiology. Plants were not considered due to lack of the appropriate guidelines for risk assessment. In addition, the resulting pest list may be refined to retain only pests with enhanced (full) datasheets, only those that affect plants and those that have been established to be invasive. For this analysis, only pests known to affect plants were retained. The enhanced datasheet and invasive options were left open. The list generated from the tool was downloaded as an excel (.xlsx) file for downstream analysis.

The list was manually assessed to remove pests that do not affect value chains of interest to Zambia and pests represented by their genera instead of species names. The final list was subjected to risk assessment by 24 Subject Matter Experts (SMEs) convened from national and international agricultural research institutions, academia and extension institutions. The SMEs had experience in the fields of bacteriology, entomology, mycology, nematology and virology acquired from diverse backgrounds including policy, regulation, industrial and academic research. The SMEs were allocated to three thematic groups, based on their expertise: Entomology, Nematology and Plant Pathology. Plant pathology included the field of Bacteriology (bacteria and phytoplasmas), Mycology (included Chromista (oomycetes and fungi) and Virology (viruses and viroids).

Description of the scoring system

The risk scoring system used was based on that described by Roy et al. (2019). This scoring system (guidelines) had been modified in previous studies by Mulema et al. (2022) and Kenis et al. (2022). Roy et al. (2019) assessed the likelihood of arrival, establishment, spread and magnitude of potential negative impact on biodiversity and ecosystem services, whereas in this assessment, the likelihood of entry (arrival), establishment and potential magnitude of socio-economic impact and potential magnitude of impact on biodiversity were assessed. The likelihood of spread was considered under establishment; however, once an alien species arrives on the African continent, exponential spread within and between countries in SSA has been observed (Guimapi et al. 2016; De Groote et al. 2020). This is majorly assisted by human-mediated activities especially if the criteria for entry and establishment are met and the key pathways[6] are available (Mahuku et al. 2015; De Groote et al. 2020). A 5-score system for the four parameters (entry, establishment, socio-economic and biodiversity impact) was used, where a score of 1 suggested unlikely to enter or establish or minimal impact and a score of 5 suggested very likely to enter or establish or major impact. The full guidelines and a description of the 5-score system for the four parameters are presented in Suppl. material 1, but briefly outlined below.

To assess the likelihood of entry, a score of 1 suggested absent from Africa and unlikely to be in the imported commodity; 2, absent from Africa, but likely to be infrequently imported on a commodity; 3, present in Africa (not in neighbouring countries) and spreads slowly; or absent from Africa, but recently spreads very fast on several continents or often associated with a commodity commonly imported or frequently intercepted in Zambia; 4, present in Africa (not in neighbouring countries) and spreads fast or in a neighbouring country and spreads slowly; and 5, present in a neighbouring country (Angola, Botswana, The Democratic Republic of the Congo (DR Congo), Malawi, Tanzania, Mozambique, Namibia and Zimbabwe) and spreads fast. To assess the likely pathways of arrival, three likely pathways as defined by Hulme et al. (2008) were considered.

6 The term "pathway" is used within the context of the IPPC and refers to any means that allows entry and spread of a pest (ISPM Number 5) (IPPC Secretariat 2021).

Hulme et al. (2008) defined three mechanisms through which alien species may enter a new geographical or political region. They included importation of a commodity, arrival of a transport vector and natural spread from a neighbouring region. The three mechanisms comprised six pathways namely, contaminant, escape and release under the importation of a commodity mechanism; stowaway under the arrival of a transport vector mechanism; corridor and unaided under the natural spread from a neighbouring region mechanism. Only three pathways were considered, contaminant, stowaway also referred to as hitchhiker and unaided, abbreviated in the tables as CO, ST and UN, respectively. Pathogenic organisms especially bacteria, viruses and viroids which could be carried by vectors, the stowaway pathway was considered although the contaminant pathway was also considered if the pathogenic organism is seed-borne[7] and seed-transmitted[8]. The stowaway pathway was also considered for soil- and refuse-borne pathogenic organisms which could unintentionally be introduced with soil or plant debris.

To assess the likelihood of establishment, a score of 1 suggested Zambia is climatically unsuitable or host plants are not present; 2, only few areas in Zambia climatically suitable; or host plants rare; 3, large areas in Zambia climatically suitable and host plant rare; or only few areas in Zambia climatically suitable, but host plants at least moderately abundant; 4, large areas in Zambia climatically suitable and host plants moderately abundant; and 5, large areas in Zambia climatically suitable and host plants very abundant. For the potential magnitude of socio-economic impact, a score of 1 suggested the species does not attack plants that are cultivated or utilised; 2, the species damages plants that are only occasionally cultivated or utilised; 3, the species damages plants that are regularly cultivated or utilised, but without threatening the cultivation, utilisation or trade of this crop; 4, the species has the potential to threaten, at least locally, the cultivation of a plant that is regularly cultivated or utilised; or to regularly attack a crop that is key for the Zambian economy without threatening this latter; and 5, the species has the potential to threaten, at least locally, a crop that is key for the Zambian economy. For potential magnitude of impact on biodiversity, a score of 1 suggested the species will not affect any native species; 2, the species will affect individuals of a native species without affecting its population level; 3, the species has the potential to lower the population levels of a native species; 4, the species has the potential to locally eradicate a native species or to affect populations of a protected or keystone species; and 5, the species has the potential to eradicate a native species or to locally eradicate a keystone species.

Scoring of species

After a group training of SMEs at the initial workshop conducted in July 2022, the scoring of species was done independently by all SMEs. In September 2022, a consensus follow-up workshop was held to review the risk assessments for each attribute one by one and any discrepancies between the scores were discussed amongst the assessors. The assessors had the opportunity to modify their scores according to the opinions

7 A seed-borne organism is any organism or pathogen that is carried in or on or with seed.

8 Seed-transmission refers to the transfer and re-establishment of a seed-borne pathogen from seed to plant.

of the other SMEs. The risk score was validated through consensus and, in cases of disagreement, the individual scores and the evidence on which they were based were re-discussed. Confidence was estimated for each score recorded for species for the likelihood of entry; establishment; potential magnitude of socio-economic impact; and potential impact on biodiversity; likely pathway of arrival; and for the overall score following Blackburn et al. (2014). The rating proposed by Blackburn et al. (2014) was originally modified from the European and Mediterranean Plant Protection Organisation (EPPO) pest risk assessment decision support scheme (OEPP/EPPO 2012). The information to support the scores and confidences and the likely pathways was obtained from CABI Compendium datasheets, peer-reviewed journal articles and reviews and grey literature (conference papers and proceedings; dissertations and theses; government documents and reports and newspaper articles). The SMEs also relied on their existing knowledge for assessing the species. The likely pathway of arrival and associated confidence levels were used to help focus discussions on the possibility of entry and establishment, but did not contribute to the overall score. Risk is a product of likelihood of an event occurring and the impact associated with that likelihood. Therefore, the overall risk score was obtained by the following formula:

$$\textit{Likelihood of entry} \times \textit{likelihood of establishment} \times \\ (\textit{magnitude of socio-economic impact} + \textit{magnitude of impact on biodiversity})$$

Scores below three were considered low risk because of their low impact on the likelihood of entry, establishment, economic and biodiversity damage; scores of three were considered moderate, while scores above 3 (4 and 5) presented a high risk because they had an opposite effect from the low scores. The overall risk score was used to rank species according to their potential threat to Zambia. A minimum score of 54 was considered as the cut-off for further consideration because such a species scored an average of three for all the assessable attributes or more than a three in at least three or more attributes. A score of three suggested a situation that was skewed towards the possibility of entry, establishment and higher impact (social-economic or biodiversity). For all assessed species, recommendations on the next course of action was made.

Results

The initial search yielded a total of 306 plant pathogenic bacteria and 10 protists. However, following a cleaning process to remove pests represented only by genus names, the list was narrowed down to 283 bacterial and 10 Protista species that were eligible for assessment (Suppl. material 2). The cleaned list comprised of 43 species reported as invasive, all of which were bacterial species. The list was further refined to focus on pests that damage value chains relevant to Zambia which resulted in a list of 137 bacteria (Suppl. material 3) and eight Protista (Suppl. material 4) species resulting in a total of 145 pests. It is this list that was subjected to rapid risk assessment using the guidelines presented in Suppl. material 1, but also briefly described in the methodology.

In addition, species, not yet reported as present in Zambia, but adjudged to be of phytosanitary concern, were added to each respective pest category although this was only possible for the bacterial species. The additional pests are highlighted in the column named "From horizon scanning" (Suppl. materials 3, 4) particularly those indicated as "N" (for NO) in the list, denoting that the given pest was not part of the original scanning process. Vectors that have been reported to transmit the assessed pest species, especially for the bacteria species were also assessed to establish their associated level of risk (Suppl. material 5). For both categories (Bacteria and Protista), 53% (n = 77 of 145) were reported in Africa. Of the 53% reported in Africa, 60% (n = 46 of 77) were reported for neighbouring countries to Zambia (Suppl. materials 3, 4). Such pests had very high overall risk scores because of their increased likelihood of entry.

Bacteria

The final bacterial list for assessment comprised 137 species as indicated above. Of these, 77 species representing a proportion of 53% were reported in Africa, with 42 of the 77 species (55%) reported in countries neighbouring Zambia. Of the 137 species, 132 (96%) species were identified through the horizon scanning process and five species (4%) were added because they presented a phytosanitary risk to agriculture and, therefore, the economy of Zambia. Sixteen percent (n = 21 of 132) of the species were recorded as invasive in some countries. The highest overall risk score was 140 recorded for *Candidatus Phytoplasma pini*, *Dickeya zeae*, *Leifsonia xyli* subsp. *Xyli* and *Xanthomonas axonopodis* pv. *vasculorum* and the lowest was 5 recorded for *Candidatus Arsenophonus phytopathogenicus*. A proportion of 66% (n = 90) could be introduced as contaminants, 24% (n = 33) either as contaminants or stowaways or both, while the least, 10% (n = 14) as stowaways. The contaminant pathway mainly comprised introduction as seed, plants for planting or plant parts, while stowaways mainly comprised vectors. Introduction through the unaided pathway was not considered likely for this group of pests.

Three of the four of the species (*Pectobacterium parvum*, *P. peruviense* and *P. punjabense*) added to the horizon scanning results belonged to the family Pectobacteriaceae (Soft Rot Pectobacteriaceae or SRP), while one, *Xanthomonas citri* pv. *aurantifolii* belonged to the family Lysobacteraceae. All added SRPs recorded an overall risk score below the suggested cut-off of 54, while the xanthomonad recorded an overall risk score above the suggested cut-off of 54 (75). Eleven percent (n = 15 of 137) of the assessed bacterial species belonged to the Phylum Tenericutes which comprises the phytoplasmas. A proportion of 54% (n = 74 of 137) of the species had full (enhanced) datasheets available in the CABI Compendium which provided access to detailed information for assessment. However, various sources of literature were used to assess the remaining 46% with only basic datasheets. Twenty-one (15%) of the assessed bacterial species are vectored, all of which were phytoplasmas, except for *C. Arsenophonus phytopathogenicus*, *Candidatus Liberibacter africanus*, *Candidatus Liberibacter asiaticus*, *Candidatus Liberibacter solanacearum*, *Pantoea stewartii*, *Spiroplasma citri*, *Xylella fastidiosa* subsp. *fastidiosa* and *Xylella fastidiosa* subsp. *pauca*.

At the considered cut-off overall score of 54 as suggested by Mulema et al. (2022), sixty-two (47%, n = 137) of the species were classified as high-scoring and hence prioritised for action (Table 1). The high-scoring species were all reported as present in Africa (57 species, 92%), except Sugarcane grassy shoot phytoplasma, Sugarcane white leaf phytoplasma, *X. citri* pv. *aurantifolii*, *X. fastidiosa* subsp. *fastidiosa*, *Xylella fastidiosa* subsp. *Multiplex* and *Xylella fastidiosa* subsp. *pauca* (*Xfp*) (Table 1, Suppl. material 3). A proportion of 70% (40 of 57 pest species) were reported as present in the neighbouring countries.

Protista

Only eight species were assessed, all of which were identified using the Horizon Scanning Tool with no protist of phytosanitary concern added from other sources. All except one, *Physarum cinereum*, had full (enhanced) datasheets available in the CABI Compendium and none had been reported as invasive in any country. Four of the species were reported as present in Africa with only two reported in the neighbouring countries of Angola, Malawi, Mozambique, Tanzania and Zimbabwe (Suppl. material 4). Considering a cut-off of 54 for the overall risk score, only three species *Plasmodiophora brassicae* (125), *Spongospora subterranea* (100) and *Polymyxa graminis* (60) had the highest overall risk score (Suppl. material 4). Although none of the assessed species could be introduced in Zambia through the unaided pathway, six of the species could be introduced through the stowaway pathway and two could be introduced through the contaminant and stowaway pathways.

Vectors and vectored species

Two of the assessed protists species, *Spongospora subterranea* and *Polymyxa graminis*, are reported vectors of Potato mop-top virus (Chikh-Ali and Karasev 2023) and various diseases of wheat, barley and groundnut viruses, respectively (Kanyuka et al. 2003). A total of eighty species were reported to vector the assessed bacterial species. Of these, 11 (18%) had been reported in Africa and were *Anguina agrostis*, *Bactericera trigonica*, *Diaphorina citri*, *Neoaliturus tenellus*, *Nephotettix nigropictus*, *Orosius albicinctus*, *Orosius orientalis*, *Pentastiridius leporinus*, *Philaenus spumarius* and *Trioza erytreae* (Table 2, Suppl. material 5). Two of these species have been reported as present in neighbouring countries, *D. citri* in Malawi and *T. erytreae* in DR Congo, Malawi, Tanzania and Zimbabwe, while *T. erytreae* has been reported as present in Zambia (Table 2, Suppl. material 5). The highest overall risk score was 125 for *D. citri*, while the lowest was 2 scored for *Aphrodes bicinctus*, *Colladonus montanus*, *Euscelis lineolatus*, *Helochara delta*, *Neoaliturus pulcher*, *Zeoliarus atkinsoni* and *Zeoliarus oppositus*. *Trioza erytreae* was not scored because it was already reported as present in Zambia as indicated above (Aidoo 2023). The assessed vectors were likely to be introduced mainly through the contaminant pathway, especially for those reported outside Africa or in Africa, but not in neighbouring countries, although the stowaway pathway was also possible for those reported outside Africa as eggs or young adults. Further, those reported in neighbouring countries were likely to be introduced as contaminant or stowaways or they could spread unaided.

Table 1. Presents bacteria and protist species identified through horizon scanning that recorded an overall score of 54 and above. The overall score is derived from the product of likelihood and impact scores. Three likely pathways; contaminant (CO), stowaway (ST), and unaided (UN) were considered. These pathways are defined by Hulme et al. (2008) under the three mechanisms through which alien species may enter a new geographical or political region. Most of the assessed parameters including likelihood and impact scores have not been included in this Table; however, they are presented in Suppl. materials 3, 4.

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Acidovorax avenae	Bacteria	Comamonadaceae		**Main hosts**: *Oryza sativa*, *Saccharum officinarum*, *Sorghum bicolor*, *Zea mays*			Y	Y	Burkina Faso, Comoros, Côte d'Ivoire, DR Congo, Egypt, Ethiopia, Gabon, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Niger, Nigeria, Réunion, Sierra Leone, South Africa, Sudan, Tanzania, Uganda, and Zimbabwe	CO	100	Detection surveillance
Candidatus Liberibacter africanus	Bacteria	Phyllobacteriaceae	Y	**Main hosts**: *Calodendrum capense*, *Citrus aurantiifolia*, *Citrus limon*, *Citrus nobilis*, *Citrus reticulata*, *Citrus sinensis*, *Citrus paradisi*, and *Poncirus trifoliata*	*Trioza erytreae*		Y	Y	Angola, Burundi, Cameroon, Central African Republic, Comoros, Eswatini, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Nigeria, Réunion, Rwanda, Somalia, Uganda, South Africa, Tanzania, Zimbabwe, and Saint Helena	CO, ST	96	Detection surveillance
Candidatus Liberibacter asiaticus	Bacteria	Phyllobacteriaceae	Y	**Main host**: *Citrus reticulata* and *Citrus sinensis*	*Diaphorina citri*		Y	N	Ethiopia, Kenya, Mauritius, and Réunion	CO, ST	72	A pest-initiated PRA to advise on import requirements.
Candidatus Liberibacter solanacearum	Bacteria	Phyllobacteriaceae	Y	**Main hosts**: *Capsicum annuum*, *Datura stramonium*, *Solanum lycopersicum*, *Solanum tuberosum*	*Bactericera cockerelli*, *Bactericera trigonica*, *Trioza*		Y	N	Morocco and Tunisia	ST	72	No action is suggested for now.

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Candidatus Phytoplasma asteris	Bacteria	Acholeplasmataceae	Y	**Main hosts**: *Allium cepa*, *Anemone coronaria*, *Anethum graveolens*, *Apium graveolens*, *Brassica napus*, *Brassica oleracea* subsp. *capitata*, *Brassica oleracea* subsp. *italica*, *Brassica rapa*, *Callistephus chinensis*, *Celosia argentea*, *Chrysanthemum coronarium*, *Chrysanthemum frutescens*, *Chrysanthemum morifolium*, *Daucus carota*, *Fragaria ananassa*, *Hydrangea macrophylla*, *Ipomoea obscura*, *Lactuca sativa*, *Limonium sinuatum*, *Paulownia tomentosa*, *Ranunculus asiaticus*, *Spinacia oleracea*, *Tagetes erecta*, *Tagetes patula*, *Trifolium hybridum*, *Trifolium repens*, and *Zea mays*	*Aphrodes bicinctus*, *Colladonus geminatus*, *Colladonus montanus*, *Dalbulus elimatus*, *Euscelidius variegatus*, *Euscelis*, *Euscelis lineolatus*, *Euscelis plebeja*, *Hishimonoides sellatiformis*, *Macrosteles laevis*, *Macrosteles quadrilineatus*, *Macrosteles quadripunctulatus*, *Macrosteles sexnotatus*, *Macrosteles striifrons*, *Macrosteles viridigriseus*, *Scaphytopius acutus*		Y	N	South Africa	CO, ST	105	No action is suggested for now. This is advised by the absence of all the reported vectors in Africa.
Candidatus Phytoplasma aurantifolia	Bacteria	Acholeplasmataceae		**Main hosts**: *Citrus aurantiifolia*	*Hishimonus phycitis*		Y	N	Ethiopia, South Africa, Sudan, and Uganda	CO, ST	54	No action is suggested for now.
Candidatus Phytoplasma oryzae	Bacteria	Acholeplasmataceae		**Main host**: *Oryza sativa*	*Nephotettix cincticeps*, *Nephotettix nigropictus*, *Nephotettix virescens*		Y	N	Kenya	ST	72	With less evidence of transmission in seed, a pest-initiated PRA may not be appropriate at the moment but conduct a detection to establish the status of the pest.
Candidatus Phytoplasma pini	Bacteria	Acholeplasmataceae		**Main hosts**: *Pinus halepensis*, *Pinus sylvestris*	Unknown		Y	Y	Mozambique	ST	140	Detection surveillance to guide on other phytosanitary measures

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Candidatus Phytoplasma solani	Bacteria	Acholeplasmataceae	Y	**Main hosts**: *Capsicum annuum*, *Lavandula angustifolia*, *Solanum lycopersicum*, *Solanum tuberosum*, *Vitis vinifera*, *Zea mays*	*Anaceratagallia ribauti*, *Hyalesthes obsoletus* Signoret; *Reptalus panzeri*		Y	N	Niger	CO, ST	90	No action is necessary for now. A pest-initiated PRA is also not necessary because the pest is not naturally seed-transmitted yet the vectors have not been reported in Africa.
Cassava witches' broom	Bacteria	Acholeplasmataceae		**Main host**: *Manihot esculenta*	Unknown		Y	N	Côte d'Ivoire	CO, ST	84	No action is suggested for now
Dickeya chrysanthemi	Bacteria	Pectobacteriaceae		**Main hosts**: *Chrysanthemum morifolium* and *Dianthus caryophyllus*			Y	Y	Algeria, Comoros, Cote d'Ivoire, Egypt, Morocco, Republic of the Congo, Reunion, South Africa, Sudan, and Zimbabwe	CO	120	Detection surveillance
Dickeya dadantii	Bacteria	Pectobacteriaceae		**Main host**: *Solanum tuberosum*			Y	Y	Comoros and Zimbabwe	CO	72	Detection surveillance
Dickeya dianthicola	Bacteria	Pectobacteriaceae		**Main host**: *Solanum tuberosum*			Y	N	Morroco and South Africa	CO	54	Detection surveillance
Dickeya zeae	Bacteria	Pectobacteriaceae		**Main host**: *Zea mays*			Y	Y	Comoros, Egypt, Mauritius, Réunion, South Africa, Sudan, and Zimbabwe	CO	140	Detection surveillance
Herbaspirillum rubrisubalbicans	Bacteria	Oxalobacteraceae		**Main hosts**: *Saccharum officinarum*, *Sorghum halepense*, *Zea mays*; **Other host**: *Sorghum bicolor*			Y	Y	Angola, Benin, Burundi, Central African Republic, Côte d'Ivoire, Madagascar, Malawi, Mauritius, Nigeria, Réunion, Tanzania, and Togo	CO	120	Detection surveillance
Leifsonia xyli subsp. *xyli*	Bacteria	Microbacteriaceae	Y	**Main host**: *Saccharum officinarum*			Y	Y	Burkina Faso, Cameroon, Comoros, Djibouti, DR Congo, Egypt, Eswatini, Ethiopia, Kenya, Madagascar, Malawi, Mali, Mauritius, Mozambique, Nigeria, Republic of the Congo, Réunion, Seychelles, Somalia, South Africa, Sudan, Tanzania, Uganda, and Zimbabwe	ST	140	Detection surveillance

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Pantoea ananatis	Bacteria	Erwiniaceae		**Main hosts**: *Allium cepa*, *Ananas comosus*, *Brassica rapa* subsp. *pekinensis*, *Citrus sinensis*, *Cucumis melo*, *Cucumis sativus*, *Fragaria ananassa*, *Oryza sativa*, *Prunus persica*, *Zea mays*	*Diabrotica virgifera virgifera*		Y	Y	Benin, Burkina Faso, Egypt, Morocco, Nigeria, South Africa, Togo, and Zimbabwe	CO	120	Detection surveillance
Pantoea citrea	Bacteria	Erwiniaceae		**Main host:** *Ananas comosus*			Y	Y	Tanzania	CO	80	Detection surveillance
Pantoea stewartii subsp. *stewartii*	Bacteria	Erwiniaceae		**Main hosts**: *Zea mays*, *Zea mays* subsp. *mays*, *Zea mays* subsp. *mexicana*, *Zea mays* subsp. *Parviglumises*, *Triticum aestivum*	*Chaetocnema pulicaria* Melsheimer		Y	N	Benin and Togo	ST	105	No action is necessary for now because the pathogen has only been reported in Benin and Togo while the vector has only been reported in Cameroon.
Pectobacterium atrosepticum	Bacteria	Pectobacteriaceae		**Main host**: *Solanum tuberosum*			Y	Y	Algeria, Egypt, Mauritius, Morocco, Mozambique, South Africa, Tanzania, Tunisia, and Zimbabwe	CO	80	Detection surveillance
Pectobacterium betavasculorum	Bacteria	Pectobacteriaceae		**Main host**: *Beta vulgaris* var. *saccharifera*, *Solanum tuberosum*			Y	N	Egypt	CO	60	A detection surveillance followed pest-initiatiated PRA
Pectobacterium brasiliense Portier et al.	Bacteria	Pectobacteriaceae		**Main host**: *Solanum tuberosum*			Y	Y	Algeria, Egypt, Kenya, Morocco, Réunion, South Africa, and Zimbabwe	CO	80	Detection surveillance
Pectobacterium carotovorum	Bacteria	Pectobacteriaceae		**Main host**: *Solanum tuberosum*			Y	Y	Algeria, Central African Republic, Egypt, Ethiopia, Libya, Malawi, Mauritius, Morocco, Republic of the Congo, South Africa, Sudan, and Zimbabwe	CO	100	Detection surveillance
Pectobacterium parmentieri	Bacteria	Pectobacteriaceae	Y	**Main host**: *Solanum tuberosum*			Y	Y	South Africa, and Zimbabwe	CO	60	Detection surveillance
Plasmodiophora brassicae	Protista	Plasmodiophoraceae		**Main hosts**: *Brassica napus*, Brassica oleracea subsp. capitata, *Brassica oleracea* subsp. *gongylodes*, *Raphanus sativus*			Y	Y	Angola, Malawi, São Tomé and Príncipe, and South Africa	ST	125	Detection surveillance

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Polymyxa graminis	Protista	Plasmodiophoraceae		**Main hosts**: *Arachis hypogaea*, *Avena sativa*, *Hordeum vulgare*, *Oryza sativa*, *Secale cereale*, *Triticum aestivum*		Streak mosaic of wheat	Y	N	Burkina Faso, Côte d'Ivoire, Mali, Niger, and Senegal	ST	60	A pest-initiated PRA to advise on import requirements.
Pseudomonas cichorii	Bacteria	Pseudomonadaceae	Y	**Main hosts**: *Apium graveolens*, *Chrysanthemum coronarium*, *Chrysanthemum morifolium*, *Chrysanthemum vestitum*, *Cichorium endivia* subsp. *endivia*, *Cichorium endivia* subsp. *crispum*, *Cichorium intybus*, *Gerbera jamesonii*, *Hibiscus rosa-sinensis*, *Lactuca sativa*, and *Vigna angularis*			Y	Y	Burundi, Egypt, South Africa, and Tanzania	CO	120	Detection surveillance
Pseudomonas corrugata	Bacteria	Pseudomonadaceae		**Main host**: *Solanum lycopersicum*			Y	Y	Egypt, South Africa, and Tanzania	CO	120	Detection surveillance
Pseudomonas marginalis pv. *marginalis*	Bacteria	Pseudomonadaceae		**Main host**: *Lactuca sativa*			Y	Y	Egypt, Ethiopia, Kenya, Nigeria, South Africa, Tanzania, and Uganda	CO, ST	60	Detection surveillance
Pseudomonas mediterranea	Bacteria	Pseudomonadaceae		**Main host**: *Solanum lycopersicum*			Y	Y	Egypt, South Africa, and Tanzania	CO	80	Detection surveillance
Pseudomonas syringae pv. *atrofaciens*	Bacteria	Pseudomonadaceae		**Main host**: *Triticum aestivum*			Y	N	Morocco, South Africa, and Zimbabwe	CO	60	Detection surveillance
Pseudomonas syringae pv. *coronafaciens*	Bacteria	Pseudomonadaceae		**Main host**: *Avena fatua*, *Avena sativa*, *Secale cereale*			Y	Y	Ethiopia, Kenya, Morocco, Zimbabwe	CO	96	Detection surveillance
Pseudomonas syringae pv. *garcae*	Bacteria	Pseudomonadaceae		**Main host**: *Coffea arabica*			Y	N	Kenya	CO	60	No action is suggested for now.

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Pseudomonas syringae pv. *maculicola*	Bacteria	Pseudomonadaceae		**Main hosts**: *Brassica juncea* var. *juncea*, *Brassica nigra*, *Brassica oleracea* var. *botrytis*, *Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *gemmifera*, *Brassica oleracea* var. *gongylodes*, *Brassica oleracea* var. *italica*, *Brassica oleracea* var. *viridis*, *Brassica rapa* subsp. *pekinensis*, *Brassica rapa* subsp. *rapa*, *Raphanus sativus*			Y	Y	Algeria, Mauritius, Mozambique, South Africa, Zimbabwe	CO	80	Detection surveillance
Pseudomonas syringae pv. *mellea*	Bacteria	Pseudomonadaceae		**Main hosts**: *Atriplex hortensis*, *Atropa belladonna*, *Datura stramonium*, *Hyoscyamus niger*, *Nicotiana alata*, *Nicotiana glauca*, *Nicotiana rustica*, *Nicotiana tabacum*, *Phaseolus lunatus*, *Solanum lycopersicum*, *Cannabis sativa*			Y	Y	Tanzania	CO	80	Detection surveillance
Pseudomonas syringae pv. *pisi*	Bacteria	Pseudomonadaceae		**Main host**: *Pisum sativum*			Y	Y	Kenya, Malawi, Tanzania, Zimbabwe, and South Africa	CO	60	Detection surveillance
Pseudomonas syringae pv. *sesami*	Bacteria	Pseudomonadaceae		**Main hosts**: *Sesamum indicum*			Y	Y	Egypt, South Africa, Tanzania, and Uganda	CO	60	Detection surveillance
Pseudomonas syringae pv. *striafaciens*	Bacteria	Pseudomonadaceae		**Main hosts**: *Avena sativa*, *Hordeum vulgare*, *Zea mays*			Y	Y	South Africa and Zimbabwe	CO	100	Detection surveillance
Pseudomonas syringae pv. *tomato*	Bacteria	Pseudomonadaceae		**Main host**: *Solanum lycopersicum*			Y	Y	Morocco, South Africa, Tanzania, and Tunisia	CO	80	Detection surveillance
Ralstonia solanacearum (Phylotype II)	Bacteria	Burkholderiaceae	Y	**Main host**: *Musa* Spp.			Y	N	Ethiopia, Libya, Nigeria, and Senegal	CO, ST	72	A pest-initiated PRA to advise on import requirements.
Spongospora subterranea	Protista	Plasmodiophoraceae		**Main host**: *Solanum tuberosum*		Potato Mop Top Virus.	Y	Y	Algeria, Burundi, Egypt, Kenya, Madagascar, Mauritius, Morocco, Mozambique, Rwanda, South Africa, Tanzania, Tunisia, and Zimbabwe	CO, ST	100	Detection surveillance

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Streptomyces scabiei	Bacteria	Streptomyces		**Main host**: *Solanum tuberosum*			Y	N	South Africa	CO, ST	54	Detection surveillance
Sugarcane grassy shoot phytoplasma	Bacteria	Acholeplasmataceae		**Main hosts**: *Saccharum officinarum*, *Saccharum spontaneum*	*Deltocephalus vulgaris*		N			CO, ST	70	A pest-initiated PRA to advise on import requirements.
Sugarcane white leaf phytoplasma	Bacteria	Acholeplasmataceae		**Main hosts**: *Saccharum officinarum*, *Saccharum spontaneum*; **Other hosts**: *Saccharum edule*, *Saccharum robustum*	*Matsumuratettix hiroglyphicus*, *Yamatotettix flavovittatus*		N			CO, ST	70	A pest-initiated PRA to advise on import requirements.
Sugarcane yellow leaf phytoplasma	Bacteria	Acholeplasmataceae		**Main hosts**: *Saccharum officinarum*	*Saccharosydne saccharivora*, *Matsumuratettix hiroglyphicus*, *Deltocephalus vulgaris*, *Yamatotettix flavovittatus*		Y	N	Morocco	CO, ST	105	A pest-initiated PRA to advise on import requirements.
Xanthomonas axonopodis pv. *cajani*	Bacteria	Lysobacteraceae		**Main host**: *Cajanus cajan*			Y	Y	Malawi and Sudan	CO	72	Detection surveillance
Xanthomonas axonopodis pv. manihotis	Bacteria	Lysobacteraceae	Y	**Main host**: *Manihot esculenta*			Y	Y	Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Comoros, Côte d'Ivoire, DR Congo, Ghana, Kenya, Madagascar, Malawi, Mali, Mauritius, Mayotte, Niger, Nigeria, Republic of the Congo, Réunion, Rwanda, South Africa, Sudan, Tanzania, Togo, and Uganda	CO	80	Detection surveillance
Xanthomonas axonopodis pv. *vasculorum*	Bacteria	Lysobacteraceae	Y	**Main host**: *Saccharum officinarum*			Y	Y	Eswatini, Ghana, Madagascar, Malawi, Mauritius, Mozambique, Réunion, South Africa, and Zimbabwe	CO	140	Detection surveillance
Xanthomonas axonopodis pv. vignicola	Bacteria	Lysobacteraceae		**Main host:** *Vigna unguiculata*			Y	Y	Botswana, Egypt, Nigeria, South Africa, Sudan, Tanzania, and Zimbabwe	CO	60	Detection surveillance

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Xanthomonas campestris pv. *armoraciae*	Bacteria	Lysobacteraceae		**Main host**: *Armoracia rusticana*, *Brassica oleracea* var. *botrytis*, *Brassica oleracea* var. *gemmifera*, *Brassica oleracea* var. *italica*			Y	Y	Zimbabwe	CO	60	Detection surveillance
Xanthomonas campestris pv. *campestris*	Bacteria	Lysobacteraceae		**Main hosts**: *Brassica juncea* var. *juncea*, *Brassica napus* var. *napobrassica*, *Brassica oleracea* var. *alboglabra*, *Brassica oleracea* var. *botrytis*, *Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *gemmifera*, *Brassica oleracea* var. *gongylodes*, *Brassica oleracea* var. *sabauda*, *Brassica oleracea* var. *viridis*, *Brassica rapa* subsp. *chinensis*, *Brassica rapa* subsp. *pekinensis*, *Brassica rapa* subsp. *rapa*, *Erysimum cheiri*, *Matthiola incana*, *Raphanus sativus*			Y	Y	Algeria, Angola, Ethiopia, Ghana, Kenya, Libya, Malawi, Mauritius, Morocco, Mozambique, Seychelles, Somalia, Tanzania, Togo, Uganda, and Zimbabwe	CO	60	Detection surveillance
Xanthomonas campestris pv. *zinniae*	Bacteria	Lysobacteraceae		**Main host**: *Tagetes erecta*, *Zinnia elegans*			Y	Y	Ghana, Malawi, South Africa, and Zimbabwe	CO	60	Detection surveillance
Xanthomonas cassavae	Bacteria	Lysobacteraceae		**Main host**: *Manihot esculenta*			Y	Y	Burundi, DR Congo, Kenya, Malawi, Rwanda, Tanzania, and Uganda	CO	80	Detection surveillance
Xanthomonas citri pv. *citri*	Bacteria	Lysobacteraceae	Y	**Main hosts**: *Citrus sinensis*, *Citrus paradisi*, *Citrus limon*, and *Citrus aurantifolii*			Y	Y	Benin, Burkina Faso, DR Congo, Côte d'Ivoire, Ethiopia, Gabon, Madagascar, Mali, Mauritius, Réunion, Senegal, Seychelles, Somalia, Sudan, and Tanzania	CO	100	Detection surveillance
Xanthomonas citri subsp. *aurantifolii*	Bacteria	Lysobacteraceae		**Main hosts**: *Citrus sinensis*, *Citrus paradisi*, *Citrus limon*, and *Citrus aurantifolii*			N			CO	75	Although this pest has not been reported in Africa, a detection surveillance is suggested before additional measures are instituted.

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Xanthomonas euvesicatoria pv. *euvesicatoria*	Bacteria	Lysobacteraceae		**Main hosts**: *Capsicum annuum, Capsicum frutescens, Solanum lycopersicum*			Y	Y	Comoros, Mauritius, Nigeria, Réunion, Seychelles, and Tanzania	CO	80	Detection surveillance
Xanthomonas euvesicatoria pv. *perforans*	Bacteria	Lysobacteraceae		**Main hosts**: *Capsicum annuum, Solanum lycopersicum*			Y	Y	Comoros, Ethiopia, Mauritius, Seychelles, and Tanzania	CO	80	Detection surveillance
Xanthomonas euvesicatoria pv. *sesami*	Bacteria	Lysobacteraceae		**Main hosts**: *Sesamum indicum*			Y	Y	Nigeria, Sudan, and Tanzania	CO	60	Detection surveillance
Xanthomonas oryzae pv. *oryzae*	Bacteria	Lysobacteraceae		**Main host**: *Oryza sativa*			Y	Y	Benin, Burkina Faso, Burundi, Cameroon, Egypt, Gabon, Gambia, Guinea, Mali, Niger, Nigeria, Senegal, Tanzania, Togo, and Uganda	CO	80	Detection surveillance
Xanthomonas oryzae pv. *oryzicola*	Bacteria	Lysobacteraceae	Y	**Main host**: *Oryza sativa*; **Wild host**: *Zizania aquatica*			Y	N	Côte d'Ivoire, Kenya, Madagascar, Nigeria, Senegal, Burkina Faso, Burundi, Mali, and Uganda	CO	60	Detection surveillance
Xanthomonas vasicola pv. *holcicola*	Bacteria	Lysobacteraceae		**Main hosts**: *Panicum miliaceum, Setaria italica, Sorghum almum, Sorghum bicolor, Sorghum halepense, Sorghum sudanense, Zea mays*			Y	N	Côte d'Ivoire, Ethiopia, Gambia, Madagascar, Niger, South Africa, and Togo	CO	75	Detection surveillance
Xanthomonas vasicola pv. *musacearum*	Bacteria	Lysobacteraceae	Y	**Main hosts**: *Ensete ventricosum, Musa* sp.			Y	Y	Burundi, DR Congo, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda	CO	60	Detection surveillance
Xanthomonas vasicola pv. *vasculorum*	Bacteria	Lysobacteraceae	Y	**Main hosts**: *Eucalyptus grandis, Saccharum officinarum, Zea mays*			Y	Y	Madagascar, South Africa, and Zimbabwe	CO	100	Detection surveillance
Xylella fastidiosa subsp. *fastidiosa*	Bacteria	Lysobacteraceae		**Main hosts**: *Cistus monspeliensis, Coffea* sp. *Erysimum* sp., *Juglans regia, Nerium oleander, Polygala myrtifolia, Prunus avium, Prunus dulcis, Salvia rosmarinus, Streptocarpus* sp., *Vaccinium corymbosum, Vitis vinifera*			N			CO, ST	56	A detcection surveillance followed by a pest-initiated PRA to advise on import requirements of key of host species.

Pest species (Preferred name)	Kingdom	Family	Invasive	Host species	Vectored by	Vector of	African countries with reports	Neighbouring countries with reports	Where the pathogenic organism has been reported in Africa	Likely pathway of arrival (CO, UN, ST)	Overall risk score	Suggested actions
Xylella fastidiosa subsp. *multiplex*	Bacteria	Lysobacteraceae		**Main hosts**: *Magnolia* x *soulangeana*, *Medicago arborea*, *Medicago sativa*, *Metrosideros excelsa*, *Myrtus communis*, *Olea europaea*, *Pelargonium graveolens*, *Perovskia abrotanoides*, *Phagnalon saxatile*, *Phlomis fruticosa*, *Pistacia vera*, *Polygala myrtifolia*, *Prunus armeniaca*, *Prunus cerasifera*, *Prunus cerasus*, *Prunus domestica*, *Prunus dulcis*, *Prunus persica*, *Quercus pubescens*, *Quercus suber*, *Retama monosperma*, *Rhamnus alaternus*, *Robinia pseudoacacia*, *Rosa canina*, *Rosa* Cluster-flowered bush hybrids, *Rubus ulmifolius*, *Salvia rosmarinus*, *Santolina chamaecyparissus*, *Spartium junceum*, *Strelitzia reginae*, *Ulex europaeus*, *Ulex minor*, *Vaccinium corymbosum*, *Vaccinium virgatum*, *Viburnum tinus*, *Vitex agnus-castus*, *Vitis aestivalis*, *Westringia fruticosa*	*Acrogonia citrina*, *Acrogonia virescens*, *Bucephalogonia xanthophis*, *Dilobopterus costalimai*, *Homalodisca ignorata*, *Oncometopia facialis*, *Philaenus spumarius*		N			CO, ST	56	A detcection surveillance followed by a pest-initiated PRA to advise on import requirements of key of host species.
Xylella fastidiosa subsp. *pauca*	Bacteria	Lysobacteraceae		**Main hosts**: *Citrus sinensis*, *Coffea arabica*, and *Olea europaea*	*Acrogonia citrina*, *Acrogonia virescens*, Bucephalogonia *xanthophis*, *Dilobopterus costalimai*, *Homalodisca ignorata*, *Oncometopia facialis*, *Philaenus spumarius*		N			CO, ST	56	A detcection surveillance followed by a pest-initiated PRA to advise on import requirements of key of host species.

Table 2. Rapid risk assessment of vectors reported to transmit bacterial pathogenic organisms identified through horizon scanning. Only vectors reported in Africa are presented. Three likely pathways; contaminant (CO), stowaway (ST) and unaided (UN) were considered. These pathways are defined by Hulme et al. (2008) under the three mechanisms through which alien species may enter a new geographical or political region. The overall score is derived from the product of likelihood and impact scores. Most of the assessed parameters including likelihood and impact scores have not been included in this Table; however, they are presented in Suppl. material 5.

Vector species	Class	Order	Family	Known host plant species	Vectored of	African countries with reports	Neighbouring countries with reports	Reports in Zambia	Distribution in Africa	Likely pathway of arrival (CO, ST, UN)	Overall risk score	Suggested action
Anguina agrostis	Chroma-dorea	Rhabditida	Anguinidae	**Main hosts**: *Agrostis canina*, *Agrostis capillaris*, *Agrostis exarata*, *Agrostis stolonifera*, *Bromus erectus*, *Dactylis glomerata*, *Festuca nigrescens*, *Festuca ovina*, *Festuca rubra* var. *commuta*, *Lolium multiflorum*, *Lolium rigidum*, *Phleum boehmeri*, *Phleum phleoides*, *Phleum pratense*, *Poa annua*, *Poa nemoralis*, *Poa palustris*	*Rathayibacter toxicus*	Y	N	N	South Africa	CO	45	No action is suggested for now because the risk score is very low and the pest is not reported in Africa.
Bactericera trigonica	Insecta	Hemiptera	Triozidae	**Main hosts**: *Apium graveolens* and *Daucus carota* subsp. *sativus*	*Candidatus Liberibacter solanacearum*	Y	N	N	Algeria, Egypt, Morocco, and Tunisia	CO, ST	15	No action is suggested for now because the risk score is very low and the pest is not reported in Africa.
Diaphorina citri	Insecta	Hemiptera	Liviidae	**Main hosts**: *Citrus aurantiifolia*, *Citrus limon*, *Murraya koenigii*	*Candidatus Liberibacter asiaticus*	Y	Y	N	Burundi, Cameroon, Central African Republic, Comoros, Eswatini, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Réunion, and Rwanda	CO, ST, UN	125	Since the pest is reported in a neighbouring country, a detection surveillance is needed to establish its stautus
Neoaliturus tenellus	Insecta	Hemiptera	Cicadellidae	**Main host**: *Armoracia rusticana*, *Beta vulgaris*	*Candidatus Phytoplasma trifolii*; *Spiroplasma citri*	Y	N	N	Algeria, Egypt, Libya, Morocco, Namibia, South Africa, Sudan, and Tunisia	CO, ST, UN	80	Since the pest is reported in a key trading partner (South Africa), a detection surveillance is needed to establish its status. This action is also underscored by the high score.
Nephotettix nigropictus	Insecta	Hemiptera	Cicadellidae	**Main hosts**: *Cyperus esculentus*, *Oryza sativa*	*Candidatus Phytoplasma oryzae*	Y	N	N	Cameroon	CO, ST, UN	80	A detection surveillance is suggested because of the high score. This is underscored by the importance of the value chain and the pathogenic organism vectored by the pest.

Vector species	Class	Order	Family	Known host plant species	Vectored of	African countries with reports	Neighbouring countries with reports	Reports in Zambia	Distribution in Africa	Likely pathway of arrival (CO, ST, UN)	Overall risk score	Suggested action
Orosius albicinctus	Insecta	Hemiptera	Cicadellidae	**Main host**: *Sesamum indicum*	Pigeon pea witches' broom phytoplasma	Y	N	N	Sudan, and Tunisia	CO, ST	80	This pest needs regulation because of the likely source of planting materials.
Orosius orientalis	Insecta	Hemiptera	Cicadellidae	**Main host**: *Sesamum indicum*	*Candidatus Phytoplasma trifolii*; Soybean phyllody phytoplasma	Y	N	N	Egypt	CO, ST	20	No action is suggested for now because the risk score is very low and the pest is not reported in Africa.
Pentastiridius leporinus	Insecta	Hemiptera	Cixiidae	**Main hosts**: *Prunus dulcis*	*Candidatus Arsenophonus phytopathogenicus*	Y	N	N	Algeria and Tunisia	CO, ST, UN	12	No action is suggested for now because the host is not likely to be present in Zambia.
Philaenus spumarius	Insecta	Hemiptera	Cicadellidae	**Main hosts**: *Onobrychis viciifolia, Prunus avium, Prunus dulcis, Prunus persica, Rubus fruticosus, Rubus idaeus, Vitis vinifera*	*Xylella fastidiosa* subsp. *fastidiosa*; *Xylella fastidiosa* subsp. *multiplex*	Y	N	N	Algeria and Tunisia	CO, ST	36	No action is suggested for now because the risk score is very low and the pest is not reported in Africa.
Philaenus spumarius	Insecta	Hemiptera	Aphrophoridae	**Main host**: *Artemisia* sp., *Onobrychis viciifolia, Prunus avium, Prunus dulcis, Prunus persica, Rubus fruticosus, Rubus idaeus, Vitis vinifera*	*Xylella fastidiosa* subsp. *Pauca*	Y	N	N	Algeria, Morocco, and Tunisia	CO, ST	100	Since the pest is reported in Africa, and with a high score, a detection surveillance is needed to establish its status is suggested and possibly a pest-initiated PRA to advise on import requirements.
Trioza erytreae	Insecta	Hemiptera	Triozidae	**Main hosts**: *Citrus aurantiifolia, Citrus deliciosa, Citrus jambhiri, Citrus limon, Citrus maxima, Citrus medica, Citrus paradisi, Citrus reticulata, Citrus sinensis, Citrus x nobilis, Fortunella* sp., x *Citrofortunella microcarpa*	*Candidatus Liberibacter africanus*	Y	Y	Y	DR Congo, Eritrea, Eswatini, Ethiopia, Gabon, Kenya, Madagascar, Malawi, Mauritius, Reunion, Rwanda, Saint Helena, Sao Tome & Principe, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe			Not assessed because the vector is present in Zambia. The only possible action could be a delimiting survey to determine extent of spread.

Suggested actions

For all the assessed pests, one of three actions was suggested to guide next steps which included conducting a detection surveillance or pest-initiated pest risk analysis (PRA) or taking no action. A detection surveillance was recommended when the pest had been reported as present in a country or countries neighbouring Zambia or a country or countries with high trade traffic to Zambia, such as South Africa. A pest-initiated PRA was suggested when the pest was affecting a value chain key to the economy of Zambia. Such a pest could be introduced as a contaminant especially through seed if it were seed-borne or seed-transmitted. However, in some situations where the pest had not been reported in Zambia, but was present in neighbouring countries, the suggested actions were a detection surveillance followed by a pest-initiated PRA. The rationale behind this was to ensure phytosanitary measures are only instituted after establishing the pest status in the country. A case in point is *Candidatus Liberibacter africanus*, which was indicated as absent in Zambia, based on available information in the CABI Compendium, yet it was reported in the neighbouring countries of Malawi, Tanzania and Zimbabwe along with the vector (*Trioza erytreae*) which is also reported as present in Zambia. For some bacterial and Protista species, a "no action" recommendation was made especially when the likelihood of entry and establishment was very low. However, for some pests, the "no action" recommendation was followed by periodic monitoring of the status of the pests especially where the low overall risk score was occasioned by a low likelihood of entry, but the likelihood of establishment, socioeconomic and environmental impact where medium (three) or high (above three) and the risk of this pest could increase with a change in likelihood of entry.

Discussion

Horizon scanning was utilised to select pest species not yet reported as present in the region at risk (Zambia) followed by an assessment of their likelihood of introduction, establishment and potential impacts on the economy and biodiversity. The approach has been used in several countries to avail key information about potential biological invasions to risk managers (Sutherland et al. 2008; Gassó et al. 2009; Roy et al. 2014; Bayón and Vilà 2019; Peyton et al. 2019), Spain (Gassó et al. 2009; Bayón and Vilà 2019) and United Kingdom (Sutherland et al. 2008). This information has enabled prevention of introduction through increased awareness to support early-warning and rapid response and contingency planning (Peyton et al. 2020). For some of the pest species provided by the Horizon Scanning Tool, only basic datasheets were available. This affected assessment of risk associated with likelihood of introduction, establishment and potential pathways of introduction. In addition, for most pest species, information on potential socio-economic and environmental impacts is lacking even in enhanced datasheets or completely unavailable. Lastly, information about some of the vectors reported to transmit some of the assessed pathogenic organisms is lacking.

For instance, *Xylella fastidioda* subspecies have been reported to be transmitted by a multitude of vectors, but information on these vectors is not available in SSA. This is why assessment of risk associated with pest species identified through horizon scanning was conducted by SMEs.

The pests that recorded high scores were those reported in Africa and mainly in neighbouring countries or countries with high traffic of trade, such as South Africa, demonstrating that the likelihood of entry is key in determining the overall risk score. More than half of the pests reported as present in Africa were reported in neighbouring countries. This indicates that Zambia needs to ensure that the status of the pests reported as absent in Zambia, but present in neighbouring countries, is correctly established. This will require collaboration of the Plant Quarantine and Phytosanitary Service (PQPS), which is the National Plant Protection Organisation (NPPO), with other key actors, such as public and private research institutions, international research organisations, academia, public and private extension delivery organisations and regional NPPOs.

Soft Rot Pectobacteriaceae (SRP) are one of the most devastating phytopathogenic organisms known to affect a wide range of crops, especially in *Solanum tuberosum*, *Zea mays* and a multitude of horticultural crops (Gallois et al. 1992; Adeolu et al. 2016; van der Wolf et al. 2021; Van Gijsegem et al. 2021). The SRPs identified through horizon scanning and assessed included *Dickeya chrysanthemi*, *D. dadantii*, *D. dianthicola*, *D. fangzhongdai*, *D. paradisiaca*, *D. solani*, *D. zeae*, *Pectobacterium aroidearum*, *P. atrosepticum*, *P. betavasculorum*, *P. brasiliense*, *P. carotovorum*, *P. cypripedii*, *P. odoriferum*, *P. parmentieri* and *P. polaris*, all of which affect *S. tuberosum*, except, *D. zeae*, *P. cypripedii* and *P. odoriferum*. All these SRPs recorded overall risk scores above 54, except *D. fangzhongdai*, *D. paradisiaca*, *D. solani*, *P. aroidearum*, *P. cypripedii*, *P. odoriferum* and *P. polaris* majorly because they had not been reported in Africa with the exception of *P. cypripedii*, which has been reported as present in South Africa. The SRPs that recorded scores above 54 have all been reported in neighbouring countries, except *D. dianthicola* and *P. betavasculorum*. It is on this basis that there was a suggestion for detection surveillance to be conducted for these pests before any phytosanitary measure is instituted. However, for the SRPs not recorded in neighbouring countries, detection surveillance was still suggested to confirm pest status, followed by a pest-initiated PRA.

The SRPs that were added because they presented a phytosanitary risk to *S. tuberosum* value chain included *D. oryzae*, *P. parvum*, *P. punjabense* and *P. peruviense*. *Pectobacterium punjabense* is a new species which was recently isolated from *S. tuberosum* (Sarfraz et al. 2018). This species was added because it is closely related to *P. parmentieri*, a species that was highlighted through horizon scanning. *Pectobacterium parmentieri* was reported in the neighbouring country of Zimbabwe and also highlighted as invasive. Both *P. parvum* and *P. punjabense* were recently elevated from *P. carotovorum*, a species highlighted by horizon scanning and reclassified into new species (Waleron et al. 2018; Pasanen et al. 2020). *Pectobacterium carotovorum* was reported in a number of countries and in the neighbouring country of Zimbabwe. *Dickeya oryzae* was recently

elevated from *D. zeae*, hence this elevation from a strain that had been highlighted through horizon scanning dictated the inclusion of *D. oryzae* in the risk assessment process. All the added SRPs recorded low overall risk score because they have not yet been reported in Africa. However, because they have been elevated from SRPs already reported in Africa and more so in neighbouring countries, detection surveillance was suggested to establish pest status.

The xanthomonad, *X. citri* pv. *Aurantifolii*, was added because, along with *Xanthomonas citri* pv. *Citri*, both cause Citrus canker disease (CCD) or Asiatic citrus canker (Gottwald et al. 2002; Gabriel et al. 2020; Naqvi et al. 2022). The disease affects several plants in the family Rutaceae particularly *Citrus*, *Fortunella* and *Poncirus* species (da Gama et al. 2018; Naqvi et al. 2022). All known commercial varieties of *Citrus* have been reported to succumb to the diseases (Gottwald et al. 1989, 2002; Vojnov et al. 2010). The economic impacts due to CCD result from stem die-back, fruit blemishes which affect the quality and eventual price and early fruit drop (Graham 2001; Gottwald et al. 2002). The two pathovars, *X. citri* pv. *aurantifolii* and *X. citri* pv. *citri* are mainly introduced into new geographical areas through the transportation of infected fruits from infested zones to production areas free of the disease (Gottwald et al. 2002; Naqvi et al. 2022). The two pathovars are considered quarantine organisms in most countries where they have not yet been reported (Schubert et al. 2001; Gottwald et al. 2002; Naqvi et al. 2022), hence the overall risk score of 75 and 100 for *X. citri* pv. *aurantifolii* and *X. citri* pv. *Citri*, respectively, was enough to instigate a suggestion of surveillance since *X. citri* pv. *citri* had been recorded in the neighbouring country of Tanzania.

One of the emerging bacterial pathogenic species of economic importance, *Xylella fastidiosa* that has now been reported in America, Asia, Europe and Oceania, but not yet in Africa, was also assessed (Baldi and La Porta 2017; Rapicavoli et al. 2018). *Xylella fastidiosa* is divided into three main subspecies, each with a specific host range, *X. fastidiosa* subsp. *fastidiosa* which causes Pierce's disease; *X. fastidiosa* subsp. *multiplex* which causes almond leaf scorch and phony peach disease; and *X. fastidiosa* subsp. *pauca* which causes citrus variegated chlorosis and olive quick decline syndrome (Sanderlin 2017; Rapicavoli et al. 2018; Greco et al. 2021). Three other subspecies, although of limited economic importance and host spectrum, also cause *X. fastidiosa* disease symptoms. They are *X. fastidiosa* subsp. *morus*, *X. fastidiosa* subsp. *sandyi* which causes oleander leaf scorch and *X. fastidiosa* subsp. *tashke* which causes leaf scorch in *Chitalpa tashkentensis* (Schuenzel et al. 2005; Randall et al. 2009; Nunney et al. 2014; Rapicavoli et al. 2018). The three major subspecies and *X. fastidiosa* subsp. *sandyi* were picked through horizon scanning and assessed. Two of these subspecies, *X. fastidiosa* subsp *fastidiosa* and *X. fastidiosa* subsp. *pauca* affect crop species (*Citrus sinensis* and *Coffee. arabica*) (Marucci et al. 2008; Bergsma-Vlami et al. 2017; Esteves et al. 2020) that are key to the Zambian economy. *Xylella fastidiosa* has the capacity to rattle the trading capacity of any country. It is a quarantine pest in most of Europe, the destination of agricultural produce from Africa and, therefore, it is essential that it is kept out of Zambia and other African countries.

Based on the results from the rapid risk assessment, the following recommendations are suggested; (1) conduct detection surveillance especially for pests reported in neighbouring countries to establish pest status before any further action, such as developing pest-initiated PRAs is conducted. Where the pest is established as present, a delimiting survey is suggested to establish the boundaries of infestation. Although not yet detected in Africa, periodic surveillance for *X. fastidiosa* should be conducted. It is also essential for funds to be allocated to conduct research on the likely vectors of this pathogen; (2) Pest-initiated PRA should be conducted for pests that cause high economic damage or may endanger trade in value chains key to the Zambian economy; (3) The risk associated with the assessed pests needs to be reviewed periodically to establish any changes and devise necessary mitigation measures. The suggested periodic review will require the establishment of a pest risk register to which these bacteria and protist species will be added. The risk registers are developed, based on the concept by the United Kingdom's Plant Health Risk Register[9], Northern Ireland's Plant Health Risk Register[10] or Finland's FinnPRIO-Explorer[11]. Lastly, the results from this assessment will support the updating of the list of regulated pests. The actions suggested will be implemented by the Zambian NPPO, Plant Quarantine and Phytosanitary Service (PQPS) working with key actors in Extension, Research and Academia.

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Supplementary material 1

All data from horizon scanning for Zambia

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Data type: docx

Explanation note: The table presents the data yield from the Horizon scanning exercise using the Horizon Scanning Tool. The initial search yielded a total of 306 plant pathogenic bacteria and 10 protists. However, following a cleaning process to remove pests represented only by genus names, the list was narrowed down to 283 bacterial and 10 Protista species that were eligible for assessment.

Link: https://doi.org/10.3897/neobiota.91.113801.suppl1

Supplementary material 2

Guidelines for scoring species

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Data type: xlsx

Explanation note: The documents includes the guildes used in making assessments for the pests.

Link: https://doi.org/10.3897/neobiota.91.113801.suppl2

Supplementary material 3

Plant pathogenic bacteria assessment for Zambia

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Data type: xlsx

Explanation note: The table presents all the 137 plant pathogenic bacteria prioritised for assessment based on value chains.

Link: https://doi.org/10.3897/neobiota.91.113801.suppl3

Supplementary material 4

Plant pathogenic protist assessment for Zambia

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Data type: xlsx

Explanation note: The table presents the 8 plant pathogenic protists prioritised for assessment based on value chains.

Link: https://doi.org/10.3897/neobiota.91.113801.suppl4

Supplementary material 5

Assessment for vector species

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Data type: xlsx

Explanation note: The table presents assessment scores for vectors known to transmit the assessed plant pathogenic organisms especially the bactria species.

Link: https://doi.org/10.3897/neobiota.91.113801.suppl5